# First searches for single top quark production with ATLAS

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**Abstract.** Searches for single top quark production in the t- and Wt-channels have been carried out in 35 pb$^{-1}$ of 7 TeV proton-proton collision data collected using the ATLAS detector during the 2010 LHC run. The t-channel analyses use events having a single electron or muon, two jets, and missing transverse energy. A cut-based analysis is used to extract an estimate of the production cross-section of $\sigma_t = 53^{+46}_{-36}$ pb, which translates to an upper limit of 162 pb at 95% confidence level. A cross-check analysis based on a multivariate likelihood function yields a similar result. This result are consistent with the Standard Model prediction of 66 pb. The Wt-channel analyses use events containing one or two leptons, jets and missing transverse energy. A 95% confidence level upper limit is set on the Wt-channel production cross-section of $\sigma_{Wt} < 158$ pb, corresponding to roughly 10 times the Standard Model prediction for this process.

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The production of single top quarks through the weak interaction is of great interest, as it provides the only means to directly probe the $Wtb$ coupling and measure the CKM matrix element $|V_{tb}|$. Many beyond-the-Standard-Model theories also predict new interactions which result in single top quark final states. In the Standard Model, single top quark production proceeds through three different production modes, as shown in Figure 1. The t-channel process accounts for most of the single top production, with a predicted NLO cross-section of 66 pb [1] in 7 TeV proton-proton collisions. At the LHC, t-channel events are predicted to have a charge asymmetry of around 2:1 due to the relative up- and down-quark content of the colliding protons. The Wt-channel mode, in which the single top quark is produced in association with a $W$ boson, has a predicted NLO cross-section of 15 pb [2] at the LHC. The s-channel process mainly proceeds from $q\bar{q}'$ initial states, so its predicted cross-section in proton-proton collisions is relatively small, at around 4 pb [1].

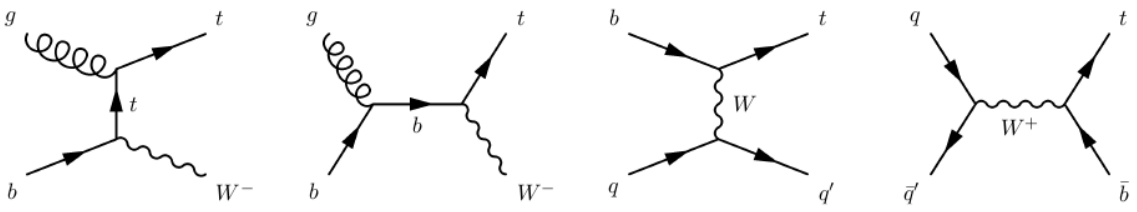


**FIGURE 1.** Tree-level Feynman diagrams for Standard Model single top quark production showing, from left to right, the Wt-channel (2 diagrams), t-channel, and s-channel processes.

The experimental observation of the combined t- and s-channel signal was first announced by the D0 [3] and CDF [4] collaborations in 2009, but detailed studies of single top production will only become possible at the LHC. These proceedings describe the first attempts to search for the t- and Wt-channel processes in data collected by the ATLAS detector at the Large Hadron Collider. Additional details can be found in [5]. The data were collected between June and October 2010 using unprescaled single electron or muon triggers and correspond to an integrated luminosity of 35 pb$^{-1}$ after the application of data quality requirements. The uncertainties quoted in these proceedings represent the combined effect of all statistical and systematic effects, where the latter include object energy and efficiency rescaling, Monte Carlo model and PDF choices, theoretical cross-sections, data-driven background estimates, and integrated luminosity.

## LEPTON+JETS ANALYSES

The t-channel and Wt-channel single lepton analyses are based on a common preselection which requires the presence of exactly one isolated electron or muon with $p_{\mathrm{T}} > 20$ GeV, 2 to 4 jets with $p_{\mathrm{T}} > 25$ GeV (exactly one of which must be b-tagged), more than 25 GeV of missing transverse energy $E_{\mathrm{T}}^{miss}$, and $M_{\mathrm{T}} > 60$ GeV$-E_{\mathrm{T}}^{miss}$, where $M_{\mathrm{T}}$ represents the transverse mass of the selected lepton and $E_{\mathrm{T}}^{miss}$. The composition of the preselected sample is obtained by combining data-driven techniques and Monte Carlo simulations. The main backgrounds at this stage, namely $W$+jets and multijet events, are determined directly from the data, whereas the contributions from single top, top pair, $Z$+jets, and diboson events are estimated using Monte Carlo simulations and normalized to their predicted theoretical cross-sections.

### t-channel selection

Two complementary analyses were developed to isolate the t-channel single top component of the preselected sample. The first requires the presence of exactly two jets, with the untagged jet satisfying $|\eta| > 2.5$. The top mass is then reconstructed using the identified lepton, b-tagged jet, and missing transverse energy, and is required to satisfy $130 < m_t < 210$ GeV. Selected events are classified depending on the charge of the lepton in order to exploit the natural charge asymmetry of the t-channel signal. We observe 21 (11) events with positive (negative) lepton charge, in good agreement with the expected total of $22.7 \pm 3.8$ ($13.2 \pm 2.8$). $10.3 \pm 1.8$ t-channel events are expected in the positive charge sample compared to $4.4 \pm 0.8$ in the negative charge sample.

The second approach also uses preselected events having exactly two jets, and is based on a likelihood function combining the power of five discriminating variables. Events having a likelihood output greater than 0.85 are selected; we observe 16 (11) events with positive (negative) lepton charge in data satisfying this condition. These values are consistent with the expected totals of $15.4 \pm 3.0$ and $8.8 \pm 2.0$ positive and negative charge events, of which $8.0 \pm 1.8$ and $3.4 \pm 0.8$ are expected to come from t-channel signal events, respectively. The detailed composition of the selected sample for each analysis and lepton species is shown in Figure 2.

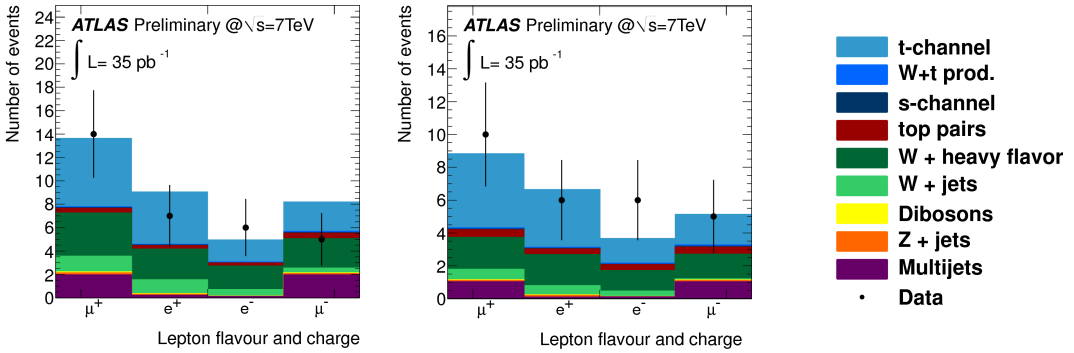


**FIGURE 2.** Number of events categorized by lepton charge and flavor for the t-channel cut-based (left) and likelihood (right) analyses.

## Wt-channel selection

The preselected sample is also used to search for Wt-channel single top events in which one of the $W$ bosons decays leptonically and the other decays hadronically. Here, we additionally demand that at least two of the selected jets be central ($|\eta| < 2.5$) and raise the transverse momentum requirement on the b-tagged jet to 35 GeV. Finally, the distance in $\eta - \phi$ space between the leading and subleading jet is required to be less than 2.5 to reduce the background from $W$+jets events. Combining all lepton flavors and jet multiplicities, 294 data events are found to survive the selection, in good agreement with the expected total of $275 \pm 50$. The Wt-channel single top content of the selected sample is estimated to be $13 \pm 2$ events.

## WT-CHANNEL DILEPTON ANALYSIS

We also search for the Wt-channel process in the dilepton final states, where both the $W$ boson from the top decay and the associated $W$ decay to a charged lepton and neutrino. Our event selection first requires the presence of exactly two isolated, oppositely-charged electrons or muons; events passing this criteria are categorized depending on the flavor combination of the two leptons ($ee/e\mu/\mu\mu$). In order to reject the large background from $Z \to ee$ or $\mu\mu$ in the dielectron and dimuon samples, we require that the invariant mass of the lepton pair $M_{\ell\ell}$ be more than 10 GeV away from the $Z$ boson mass, and demand at least 50 GeV of missing transverse energy. Electron-muon events, on the other hand, must satisfy $H_{\mathrm{T}} > 160$ GeV, where $H_{\mathrm{T}}$ is the scalar sum of the lepton transverse momenta, jet transverse momenta, and missing transverse energy. Finally, we ask that selected events contain exactly one jet with $p_{\mathrm{T}} > 20$ GeV in order to reduce the large background from $t\bar{t}$ events.

The composition of the selected sample is obtained from a combination of data-driven techniques and Monte Carlo simulation. The background from events with non-prompt or 'fake' leptons and the residual background from $Z \to ee/\mu\mu$ in the dielectron and dimuon channels are estimated from data. The $t\bar{t}$ background prediction from Monte Carlo is corrected using a purified control region defined by requiring at least two high-

$p_{\mathrm{T}}$ jets instead of exactly one jet. For the remaining backgrounds ($Z \to \tau\tau$ and diboson), we obtain the acceptance of the event selection from simulation samples and convert it to an event yield prediction using the theoretical cross-section and measured integrated luminosity.

Combining the $ee$, $e\mu$, and $\mu\mu$ samples, we observe 15 data events passing the event selection, consistent with the expected total of $15.5 \pm 4.2$ events. The Wt-channel single top content of the selected sample is estimated to be $2.8 \pm 0.8$ events.

## RESULTS

We treat the extraction of the t-channel and Wt-channel cross-sections as counting experiments and model the measurements using extended likelihood functions. The effect of statistical and systematic uncertainties on the cross-section measurements are estimated by forming the likelihood ratio and profile likelihood ratio, respectively.

Using the results of the cut-based analysis, we estimate the cross-section for t-channel single top quark production to be $\sigma_t = 53\ ^{+27}_{-24}(\mathrm{stat})\ ^{+38}_{-27}(\mathrm{syst}) = 53\ ^{+46}_{-36}$ pb. The likelihood analysis yields a consistent result with a similar overall precision. The signal significance relative to the background-only hypothesis is found to be at the level of 1.6 standard deviations; we therefore also calculate an upper limit on the production cross-section. At 95% confidence level, we find $\sigma_t < 162$ pb. The largest contributors to the systematic uncertainty in both analyses are the jet energy scale and b-tagging uncertainty, along with the data-driven $W$+jets normalization procedure.

The lepton+jets and dilepton Wt-channel analysis results are combined and used to set an upper limit on the anomalous production of $Wt$ events. The expected 95% confidence level upper limit from the combined estimate, obtained by setting the observed event yields equal to the sum of all signal and background predictions, is found to be $\sigma_{Wt} <$ 94 pb, corresponding to 6.4 times the Standard Model prediction, while the observed limit falls at 158 pb. This estimate is still highly statistically limited at this stage, but the effect of systematic uncertainties on the observed and expected limits is also important, particularly the jet energy scale (in both analyses), b-tagging (lepton+jets), and initial/final state radiation modeling (dilepton).

Siginificant improvements to both of these results should become possible very shortly, thanks not only to the much larger dataset accumulated by ATLAS so far in 2011, but also to the implementation of more sophisticated analysis techniques.

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